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Economic evaluation of a technological leap in the sector of train control and signalling: the case of German regional lines

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Abstract

This paper addresses the question of the economic benefits deriving from the application of satellite-based technologies in the rail sector, in particular in regional lines. The introduction of these technologies can generate a re-design of the control systems in the rail sector, reducing investments and operating costs, and increasing the capacity of railway lines, especially in the regional and local market. Therefore, it can be a source of efficiency for involved operators, increasing competitiveness and economic returns.
The objective of this paper then is to present and discuss the results of the economic evaluation of the potential benefits deriving from the introduction of technologies based on the Global Navigation Satellite Systems (GNSS) on the ERTMS/ETCS level 2 systems, adapted for regional lines, focusing on the German case study.
The results presented in the paper come from a study of the wide program of researches promoted by ESA for the development of satellite technologies in the rail sector; in particular, it is part of the 3inSat "Train Integrated Safety Satellite System" Demonstration project". The study has been realized with the close collaboration of Ansaldo STS, ESA, Deutche Bahn Netz and DLR (German Aerospace Agency).

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Keywords: Cost-Benefit Analysis; transport systems; rail transport; train control and signaling

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1. Introduction

This paper is aimed at illustrating the evaluation of the introduction of satellite-based technologies in control and signaling in the regional rail network, focusing on the case of German regional railways.

The satellite-based solution for train control and signaling is based on the “virtual balise” concenpt and aims at providing a solution complying with ERTMS Level 2 standards. In fact, the purpose and approach of the evaluation is that of a comparison with alternative ERTMS Level 2 solutions based on fixed balises.

The virtual balise concept involves the use of the enhanced positioning service provided by the satellite sector in order to locate the train, instead of the fixed balises between the tracks; and it is coupled with the use of a public GSM network for the radio communications between trains and the central control (Radio Block Center) rather than the GSM-R (GSM dedicated to rail).

The main impact of the virtual balise concept as compared to fix-balises is the removal of the track-side equipment and its connected costs. Obvisouly the introduction of satellite-based ERTMS generates a relevant number of upfront and operating costs. However, the complexity of Train Control Systems and their evolution in European countries (cfr. Vincze 2006) suggests to focus on cost elements which are remarkably different from one ERTMS solution to another.

The aim of the analysis is to investigate the economic impact for the rail transport system in general, however it also addresses impacts for specific operators, as this is particularly relevant for the future deployment of the satellite-based system.

2. Methodology

2.1. Approach

The evaluation of the introduction of the GNSS-based control system in the German regional network uses the following approach:

1) Division of the German regional network into a (limited) set of homogenous parts, according to the following line standards.
   a. R120 (4971 km)
   b. R80 (4639 km)
   c. G50 (287 km)
2) Derivation of unit figures with the contribution of DLR in a theoretical 100 km lines (by line standard)
3) Application of a Cost-Benefit Analysis, using the above mentioned unit figures, to the whole parts (by line standard)
4) Sum up the results by part into the overall network (some 12000 km line)

It is to be taken into account that the current solutions for train control and signaling in the German network consist of conventional signalling system (Ks-System) with line-side signals and intermittent automatic train protection (PZB); the alternative solutions accounted for in this evaluation, called ETCSL2oS, consists of a balise-based system complying with ERTMS Level 2, without line signals.

2.2. Cost-Benefit Analysis

Cost Benefit Analysis (CBA) is a tool for identifying and monetizing the impacts of an investment decision in order to determine the project costs and benefits; the aggregated results can support conclusions on whether the project is desirable and worth implementing.

The difference with a Financial Analysis is that the latter considers the “private” point of view of the subjects who run the project/operations (and/or make it feasible); whereas CBA uses the “public” point of view, in that it compares differential costs and benefits that may include non-market elements (e.g. externalities), and which are borne or taken by the community. As a result, the cost benefit analysis evaluates the contribution to the economic welfare of the region or country introduced by the project. It is an evaluation that considers the benefits of the whole society instead of just the owners' benefits deriving from the infrastructure or the transport project, as in the financial analysis.

Therefore, a first essential aspect is the identification of the scope of the analysis, in terms of (i) the subjects whom cost/benefits are associated to (technology producers, RUs, IMs, forwarders and shippers) in order to take into account all relevant impacts and avoid duplications; (ii) the geographical scope of the analysis, which will coincide, in the first stage, with the ones involved by the application of the project (in the first phase: a local low density line in Sardinia; in the second stage, with Italy and the EU (by means of an extension of the results in proportion to the corresponding market and line features).

The application of CBA relies on the construction of a scenario analysis that identifies the costs and benefits in the project scenario as opposed to costs and benefits in a baseline scenario in which the envisaged investment does not take place, so that the running of rail operations continues with current technology and management.

The following economic performance indicators can be determined with respect to the project:

- Economic net present value (ENPV): should be greater than zero for the project to be desirable from an economic standpoint. From a mathematical point of view ENPV is:

$$ENPV = \sum_{t=0}^{t=n} \frac{(B_t - C_t)}{(1+r)^t} \tag{1}$$

where:
$ENPV$ = Economic Net Present Value
B_t = Benefits (inflows) in year t
C_t = Costs (outflows) in year t,
r = Discount rate

- Benefit/Cost ratio (BCR): should be greater than one. It is calculated by dividing the present value of Costs for the present value of Benefits. In mathematical terms:

$$BCR = \frac{\sum_{t=0}^{t=n} \frac{(B_t)}{(1+r)^t}}{\sum_{t=0}^{t=n} \frac{(C_t)}{(1+r)^t}} \tag{2}$$

The analysis is performed along a 35 year time horizon (which is the span assumed for the implementation and then the operating life of the solution) and it employs a 3.5% discount rate according to the EC guidelines (European Commission, 2008).

2.3. Definition of costs and benefits

The following tables illustrates the list of costs and benefit items taken into account for the analysis.

Table 1. Cost items.

Category	Cost item	Specific cost
Investment cost	Ground equipment	ERTMS planning, installation and interfacing
Investment cost	Ground equipment	ERTMS central control (Radio Block Center)
Investment cost	Ground equipment	TAL-Server
Investment cost		Validation and proof of safety
Investment cost	Board equipment	On Board Unit
Operating cost	Ground equipment	Maintenance of ground equipment
Operating cost	Ground equipment	Maintenance of track-side equipment (balises)

It is worth underlining that the items are represented by "costs avoided", i.e. the investment and operating costs of the baselines scenarios which do not occur in the project scenario.

Other benefits, relevant for the wider community outside the rail transport system, do not seem to be relevant in this application: in fact, benefits such as the reduction of external costs of transport deriving from the modal shift from road to rail are assumed to occur as a consequence of the increased competitiveness of the rail transport system, as well as benefits for the reduction of accidents occur as a consequence of the increased safety. This is not the case in a case where the baseline scenario also includes state-of-the-art solutions which are characterized by comparable levels of competitiveness and safety.

Also not taken into account because they occur in both scenarios with negligible differences are telecommunication costs and personnel costs. Finally, no cost is assumed for the use of the EGNOS service (enhanced satellite positioning service), because this is provided for free in the aviation sector and the same is envisaged in the rail domain.

As concerns the assumptions on unit figures:

- Ground investment cost per km are estimated basing on unit figures provided by a provider of train control systems;
- RBC (Radio Block Centre) unit cost is quantified according to Certet (2013);
- TAL-S unit cost is estimated basing on Ansaldo STS data; TAL-Server is what differentiates the GNSS scenario in that it is the interface between RBC and EGNOS.
- Validation / proof of safety: the cost is based on Certet (2013). Each "project" is assumed to involve all types of lines in the same area
- The unit cost of the On-Board Unit is quantified as per fig.1.
- Maintenance of ground equipment: 1% per year of corresponding investments. For the MAR module (see fig. 2) the yearly cost is 10% of the correspongin investment.
- Maintenance of balises and BTM. An economic model based on historical data, available for an operator that has already been operating a system in which balises are included (RFI). The model for the estimation is applied according to the following logical scheme:

1) Estimation of the number of yearly failures of the BTM-balise communication in the German regional network. According to RFI data for the ETR500 operations on the network covered by balise-based systems, 177 failures in the balise-BTM communication per year are reported, with some 5000 trains/day running, some 12000 km and some 250000 balises. Considering that the ETR500 operates on high speed networks rather than regional and local ones, it is more appropriate to use as a unit parameter the number of failures calculated on the sheer number of kms of the network rather than on the trains/day or the number of balises; it is found a figure of 0.022 failures per km per year. The unit data can then be applied to the figures of the German regional network concerned by the project to find a total 66 failure per year.

2) Assumption on the average number of yearly breakdowns of balises. As mentioned, this number of failure includes breakdowns of the balises and the BTMs. The distribution between the two is derived from the same set of RFI data, based on which balise failures account for 65% of the total. However, since regional and local lines are involved in this study, a corrective factor is computed in order to take into account the higher probability of malfunctions due to climate, theft or vandalism compared to the high speed network. This factor is assumed to be equal to 1,5 and then subject to a sensitivity analysis. The total number of interventions for Eurobalises maintenance is therefore estimated in 43 per year.

3) Estimation of the average cost of intervention for balise maintenance. For each intervention on balises:
   → the personnel costs equals 150 euro (a 2-men team is involved at a cost of 25 €/hour per man, and with a Mean Time To Repair of 3 hours).
   → the cost of circulation delay can be assessed based on operators' data in some 64 euro per minute of delay, therefore 11520 Euro per intervention.
   → the balise substitution has a cost of 900 euro for the device itself and 90 euro for its storage cost. So that the total cost is 12660 Euro per intervention.

4) Calculation of the total yearly cost for balise maintenance in the German regional network. Given the unit cost of intervention estimated in (3) and the yearly number of breakdowns estimated in (2), the total yearly cost for balise maintenance in the network is therefore estimated at 540.574 Euro per year.

5) Calculation of the average yearly maintenance cost per balise. Having estimated a number of 5572 balises for the scope of this project (assuming an average figure of 1.5 balises per km), the unit cost of maintenance per balise can be calculated in 97 Euro per balise per year. Correspondingly, the balise maintenance cost per km is equal to 146 euro per km per year.

This procedures also yields the maintenance cost of BTM. The malfunctions in the balise-BTM communications also include failures of the BTM. The intervention on BTMs last longer than interventions on balise (6 hours) and they generate delay costs as well, which however can be in some instances carried out at night time, so that an average 3 hours delay will be assumed in this analysis. The cost per intervention on BTMs is therefore estimated in 300 euro in terms of personnel, and in 11520 euro in terms of delay costs, so that in total it equals 11820 euro per intervention, with an average 15 interventions per year.

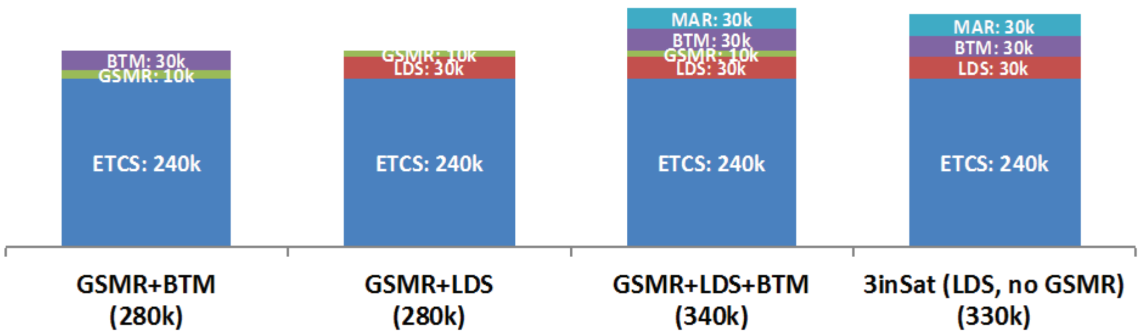

Fig. 1. Comparison of unit costs of different OBU layouts (elaboration on operators' data).

NB: the project scenario involves the "3inSat (LDS, no GSMR)" option; the baseline scenario involves the "GSMR+BTM" option.

To recap, the following unit figures for the investment and operating costs in the three scenarios are considered. NB: Figures indicated with "n.d." are busjcet to a non disclosure agreement with the providers.

Table 2. Unit cost figures in the project scenario.

Category	Cost item	Unit	R120 lines	R80 lines	G50 lines
Investment	Ground	Euro/km	202.000	225.000	227.000
Investment	RBC	Euro/ 200 km	n.d.	n.d.	n.d.
Investment	OBU	Euro / traction unit	n.d.	n.d.	n.d.
Investment	TAL-S	Euro/ 200 km	n.d.	n.d.	n.d.
Investment	Validation / proof of safety	Euro/ project	1.000.000	1.000.000	1.000.000
Operating	EGNOS	Euro / train	-	-	-
Operating	TLC	Euro / station	-	-	-
Operating	Eurobalises (incl.maint.)	Euro / balise	-	-	-
Operating	Maintenance ground	%	1%	1%	1%
Operating	Running MAR	%	10%	10%	10%

Table 3. Unit cost figures in the baseline scenario.

Category	Cost item	Unit	R120 lines	R80 lines	G50 lines
Investment	Ground	Euro/km	216.500	241.000	235.000
Investment	RBC	Euro/ 200 km	n.d.	n.d.	n.d.
Investment	OBU	Euro / traction unit	n.d.	n.d.	n.d.
Operating	TLC	Euro / station	-	-	-
Operating	Eurobalises (incl.maint.)	Euro / balise	97	97	97
Operating	Maintenance of BTM	Euro / intervention	11.820	11.820	11.820
Operating	Maintenance ground	%	1%	1%	1%
Operating	Running MAR	%	10%	10%	10%

3. Results

The application of such unit figures in the time horizon yields the following results.

- For the R120 lines:
  - Investment costs in 5 yearsNPV 319.3 million Euro
  - Operating costs in 30 years NPV 63.0 million Euro
  - Avoided investment costs NPV 331.0 million Euro
  - Avoided operating costs NPV 74.7 million Euro

  The resulting project ENPV equals 23.5 million Euro, the BCR is 1.06.

- For the R120 lines:
  - Investment costs in 5 yearsNPV 325.3 million Euro
  - Operating costs in 30 years NPV 64.3 million Euro
  - Avoided investment costs NPV 338.3 million Euro
  - Avoided operating costs NPV 73.8 million Euro

  The resulting project ENPV equals 22.5 million Euro, the BCR is 1.06.

- For the G50 lines:

- Investment costs in 5 yearsNPV 20.0 million Euro
- Operating costs in 30 years NPV 3.8 million Euro
- Avoided investment costs NPV 19.6 million Euro
- Avoided operating costs NPV 4.3 million Euro

The resulting project ENPV equals 56.9 thousand Euro, the BCR is 1.00.

4. Conclusions

The CBA application for complex technological systems as the control/signaling solutions has been adapted to the case of German regional network by considering only cost items whose differences between the project and the baseline scenarios are relevant.

The most problematic part of the analysis is the estimation of individual cost figures; the difficulty derives from the unavailability of data both because for the project scenario some elements of the system and architecture are not yet defined and because for the baseline scenario some elements are not included as is in the economic accounting of operators. A number of estimations needs to be fine-tuned and will be in future research projects, most notably the telecommunication costs when replacing a GSM-R base telecommunication with a public GSM one. Also, the economic model of balises will be fine-tuned and further types of impacts will be monetized, such as the possible reduction of braking due to the introduction of the virtual balise concept.

However, the present evaluations confirms that most of the benefits derive from the removal of track-side equipment (balises).

In general, the main advantage of the satellite-based solution is that it allows to achieve, where needed, a remarkable increase of safety at a lower cost than other upgrade solutions. Such safety impact is relevant in the contexts where current systems do not ensure safety standards like SIL4, on par with more advanced technologies.

The satellite-based system requires high investment costs both for infrastructure managers (for planning, installation and interfacing of ERTMS, for Radio Block Centres and for validation/proof of safety before implementation projects) and rail operators (On Board Units which include the Location Determination System and the Mobile Access Router in addition to the ETCS component). Such remarkable upfront costs (which are comparable with other solutions) are a weakness for a project, especially in contexts where the decision is not about which upgrade solution to implement but whether to actually invest in an upgrade. Moreover, the returns of this investments are immediately visible in the balance sheets of infrastructure managers via the cost savings of board equipment, whereas the returns for railway undertakings are mostly indirect, being connected to the decisions of railway undertakings to apply lower charges and in general to the increased attractiveness of the rail sector as compare to other transport solutions.

The introduction of technologically advanced solutions will however improve the efficiency of rail operations and this translates on the quality and cost of the services, especially in regional cross-border services where homogenous signalling systems will reduce investment and operational costs. Capacity optimization will also allow train operators to face lower tariffs, with ripple benefits for all the rail sector, especially for railway undertakings who face upfront costs for the implementation of the service.

As far as the supply side is also concerned, it is important to remark that the ERTMS program is a European Commission’s project, so that the investments in technologies will be supported in the context of the future transport policies of the supra-national, national and regional governments. In fact, due to the environmental and financial sustainability related to the introduction of these technologies in rail transport, and due to the fact that they may achieve results in terms of higher capacity, efficiency and safety of the rail transport system, they are part of the strategy for transport that future governments at different geographical levels will design and implement. They would in particular contribute to help governments to contain the need of new, financially burdensome, investments in rail infrastructure.

For example, the TEN-T Regulation No 1315/2013 requires the deployment of ERTMS on TEN-T core and comprehensive networks by the years 2030 and 2050, respectively. A recent (May 2014) amendment to the “Commission Decision 2012/88/EU on the technical specification for interoperability relating to the control-command and signaling subsystems of the trans-European rail system” makes it mandatory, in the case of both new vehicles and upgrading or renewal of existing vehicles, to fit ERTMS/ETCS on-board vehicles.

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